Surface Wave Dynamics in the Coastal Zone

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LONG-TERM GOALS

The proposed work will contribute to the improvement of existing third-generation (3G) wave models as well as to the development of the next generation of numerical wave modeling capability. The results will be applicable in the coastal zone from deep water up to and including the surf zone. Our efforts will focus on analyzing high quality datasets to support further development of the source terms for triad interactions (Snl3), depth induced wave breaking (Sbrk) and bottom friction (Sbot) in the near-shore zone.

OBJECTIVES

The scientific or technological objectives of this project are to understand the physical processes of the evolution of wind waves in the coastal zone and develop accurate parameterisations of these processes for application in numerical wave prediction models.

APPROACH

The proposed work is subdivided in five main work packages (WP).

1) Assembly of high quality data set;
2) Analysis of spectral evolution;
3) Development of a source term for wave breaking in shallow water;
4) Development of a source term for triad interactions.
5) Improvement of source terms for bottom friction.

The key individuals are:

Dr. Gerbrant van Vledder, Alkyon Hydraulic Consultancy & Research, now part of Arcadis Netherlands BV, Marknesse, The Netherlands and Delft University of Technology, Delft, The Netherlands. PI, project management and shallow water wave modelling.

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Dr. L.H. Holthuijsen, Delft University of Technology, Delft, The Netherlands. PI, development of source terms and model validation.

James Salmon, Ms.S., Delft University of Technology, Delft, The Netherlands (source term development and wave modelling);

Dr. Kevin Ewans, Shell International, Exploration and Production, Rijswijk, The Netherlands (now transferred to Kuala Lumpur, Malaysia). PI, spectral analysis and data selection.

Dr. Marios Christou assisted by Mr. Emile van der Borch, Shell International, Exploration and Production, Rijswijk, The Netherlands PI, spectral analysis and data selection.

Dr. Gerbrant van Vledder now works at BMT Argoss, Marknesse, The Netherlands, but is contracted by Arcadis Netherlands for this work.

The work is done in close cooperation with Dr. Jeff Hanson, Field Research Facility, Kitty Hawk, NC, USA. Their activities are reported separately.

WORK COMPLETED

Collection of data sets

TU Delft and Alkyon extended their collection of shallow water wave data suitable for the calibration and verification of newly developed source terms for wave breaking, bottom friction and triad interactions. This set comprises wave flume and field data. Below an overview is provided of the most relevant data set collected sofar. Full details are provided in the manuscript now being prepared (Holthuijsen and Salmon, 2011): Results will be presented at the 12th Int. Workshop on Wave Hindcasting and Forecasting, Kona, Hawaii, USA, 29-Oct – 5 Nov. 2011. Sofar, the list comprises:

- Wave flume data obtained from HR Wallingford, sloping bottoms with uni-modal and bi-modal spectra;
- Wave flume data obtained from Imperial College; sloping and horizontal bottoms;
- Boers (1995) wave flume data for a barred beach;
- Battjes-Janssen (1978) experiment wave flume data.
- Wave flume data from Aalborg University (Jensen, 2001), steep slope and horizontal bottoms.
- Field data from the Dutch Wadden Sea, Lake Sloten and Lake IJssel and the Australian Lake George for shallow water conditions were collected and arranged for verifying SWAN model results.
- Field data collected near Guam, courtesy of Jane Smith, USACE.
- Field data obtained from the FRF, courtesy of Jeff Hanson collected during hurricanes
- Field data from the Dutch coastal location at Petten.
- Field data from the Haringvliet estuary in the Netherlands.
- Field data collected by Shell in shallow water collected in the Southern North Sea.

Development of source term for wave breaking

Holthuijsen and Salmon extended the source term for wave breaking by including effect of directional spreading and a memory function. They also continued carrying out computations with γ formulations in the BJ model from the literature for a variety of situations with (flat) sloping and horizontal bottom profiles, naturally and schematically varying bottom profiles, and with wind and without wind. The observations and the computational results thus collected showed a certain tendency in the behaviour of the waves. Having studied these tendencies, they suggested a scenario for waves entering shallow water from deeper water, leading to an analytical expression for γ as a 2D function of bottom slope n and normalised depth kd (called the n-kd model).

During the last year their model has been extended with a dependency on directional spreading. In addition a memory function has been built in to better reproduce dissipation rates in strongly variations condition. This parameterization has now been implemented in the SWAN model and it is calibrated and verified against a large range of shallow water conditions obtained from laboratory and field cases. One aspect of this model is that it reconciles the seemingly contradictory high and low γ values in the literature for horizontal bottoms (with variations from 0.51 to over 1.0). The scatter in these (calibration) cases reduced typically by 50% compared with the scatter index for the conventional value γ=0.73 (from 0.13 to 0.62) while the growth curve for very shallow water were further improved compared to previous results.

The calibrated model was subsequently verified with independent laboratory observations with flat and bar-trough bottom profiles, reef cases and natural bottom profiles and with field observations under conditions of increasing complexity. The extended n-kd model was verified for field cases, obtained in the Dutch Wadden Sea, Lake George, Duck, Petten and Haringvliet. Also for these areas we found that the n-kd model outperforms the default setting of the Battjes-Janssen model with γ=0.73.

Bottom friction and wind drag

The JONSWAP bottom friction coefficient has been revisited by Van Vledder and Holthuijsen to inspect the different values recommended for swell and wind sea dominated cases. To that end the source term balance for the January 1976 storm in the North Sea, on which the high (wind sea) value is based, has been studied in detail, resulting in a recommendation to use the lower (swell) value in combination with a new parameterisation of the wind speed dependent drag formulation for use in the source term for wind input. Support for the lower value was obtained from cases in Lake George and the Wadden Sea.

Spectral analyses

Shell (Christou) performed detailed spectral analyses of new shallow water wave measurements (via AWACs) that have been recorded at the Field Research Facility in Duck, North Carolina, USA. The analysis performed is threefold. First, the measured probability distributions are compared to theoretical shallow water distributions. Second, the evolution of the frequency-direction spectrum in both the cross shore location and in time is examined. Third, the infragravity wave energy present is compared to the Ideal Surf Beat (IDSB) numerical wave model. Results will be presented at the end of 2011.

Analysis of southern North Sea data

Shell (Van der Borch) performed a comparison of wind speed and integral wave parameters between the SNEXT shallow water hindcast dataset (commonly used by a consortium of oil exploration

companies) and measured wave data from Shell's AWG platform in the southern North Sea has been undertaken to identify any differences during storm events. In total data from 4 storm events between 2006 and 2008 have been compared, which resulted in the following:

- When Hs exceeds a certain threshold SNEXT seem to overpredict Hs
- SNEXT underpredicts Hs and T2 in smaller events
- SNEXT Wind speed is systematically greater than measured Wind speed at AWG
- In some cases SNEXT Wind direction differs significantly from measured Wdir at AWG

The differences shed light on shortcomings in present day wave models which will be used for subsequent shallow water wave model improvements.

Secondly SNEXT 2d wind fields have been provided to NOPP as input for shallow water wave model runs.

RESULTS

The collection of shallow water wave flume data has been extended and rearranged with additional data for the verification of new parameterisations of shallow water processes.

A new parameterisation for wave breaking in shallow water over sloping and flat bottoms was extended with a dependence on directional spreading and a memory and implemented in the SWAN model.

A reanalysis of the Jan. 1976 (Texel) storm suggests that the 'lower' JONSWAP bottom friction value factor of C_b=0.038 m^2s^{-3} is also applicable to wind driven seas in combination with a new formulation for the dependence of the wind drag coefficient Cd on wind speed.

Time series analysis provided insight in shallow water wave height probability function, the evolution of 2D-spectra in the surf zone and the generation of infra-gravity wave energy.

An analysis of southern North Sea data has resulted in a dataset of 4 events for which 2D-wind field have been prepared for further use by NOPP participants.

IMPACT/APPLICATIONS

Improved wave prediction capabilities in shallow water are important for the design of coastal stuctures, marine activities and prediction of coastal processes. Wave information is also used in conjunction with flow models and morphological models. Especially in the coastal zone two-way wave-current interactions play a significant role in prediction surge levels.

RELATED PROJECTS

Coastal Wave Observations at FRF, Kitty Hawk, NC, USA. This project is carried out by Jeff Hanson, Kent, Hathaway and Harry Friebel. Their first aim is to collect high quality wave measurements at the FRF using a wide set of instruments and for a large range of wave conditions. Their second objective is

to perform detailed analyses of measurements to characterise the data and to select relevant wave events for model development and validation. Their third objective is to verify shallow water wave models like STWAVE and SWAN. Their fourth objective is dissimination measured data. Recently they distributed results of hurricane Earl. See http://www.frf.usace.army.mil

Modeling Wind Wave Evolution from Deep to Shallow Water; Nonlineary and Dissipation. Grant N0014-10-1-0453. PI's: Tim Janssen (San Francisco State University), Tom Herbers (Naval Postgraduate School) and Gerbrant van Vledder (Delft University of Technology). The focus of this project is to develop new parameterization for triads and quadruplets in the coastal zone (including a gradual transition between the two), and dissipation by depth-induced wave breaking and mud-damping.

SWAN development team, Delft University of Technology, Delft, The Netherlands. http://www.swan.tudelft.nl

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PUBLICATIONS

Van Vledder, G.Ph., M. Zijlema, and L.H. Holthuijsen, 2010: Revisiting the JONSWAP bottom friction formulation. Proc. 32nd Int. Conf. on Coastal Engineering, Shanghai.